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Advanced Visualization for Operational Assessment

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Combined Air and Space Operations Centers (CAOC) have traditionally relied on combat assessment to evaluate operational effectiveness. However, a more flexible model of operational assessment (OA) is required to achieve continued maturation of an Effects-based Operations (EBO) approach. Such a model will account for non-military considerations: Political, economic, social and infrastructure dimensions. It also will allow assessors to consider asymmetric factors such as counter-insurgency and terrorism control in assessing effectiveness. Unfortunately, OA currently receives relatively little attention, and there are few tools to support OA focused on effects rather than attrition. We carried out an analysis of Effects-based Assessment (EBA), focusing on information requirements and data needs, decisions and their critical cues, and common errors. We then developed a model of the work management, organization, products and cognition of EBA. In this paper, we will describe our cognitive systems engineering methodology used to analyze EBA and the findings that constitute our understanding of the process.

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Advanced Visualization for Operational Assessment

Topics:
C^2 Concepts and Organizations
C^2 Analysis
Cognitive Domain Issues

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Advanced Visualization for Operational Assessment

Combined Air and Space Operations Centers (CAOC) have traditionally relied on combat assessment to evaluate operational effectiveness. However, a more flexible model of operational assessment (OA) is required to achieve continued maturation of an Effects-based Operations (EBO) approach. Such a model will account for non-military considerations: Political, economic, social and infrastructure dimensions. It also will allow assessors to consider asymmetric factors such as counter-insurgency and terrorism control in assessing effectiveness. Unfortunately, OA currently receives relatively little attention, and there are few tools to support OA focused on effects rather than attrition. We carried out an analysis of Effects-based Assessment (EBA), focusing on information requirements and data needs, decisions and their critical cues, and common errors. We then developed a model of the work management, organization, products and cognition of EBA. In this paper we will describe our cognitive systems engineering methodology used to analyze EBA and the findings that constitute our understanding of the process. We then will offer a visualization system designed to enhance the OA team's understanding of operations as they relate to the complexity of effects in EBO, that is, to desired and undesired effects, n^{th}-order effects and kinetic versus non-kinetic effects.

Introduction

The Air Force is in the midst of a technology transition that will enable and support operators in their decision making strategies by enabling them to have access to the information needed, in a timely manner, to maintain situation awareness over the battlespace, and to work jointly with other commands. The overarching goal of this transition is to provide a network-centric warfare (NCW) capability that in military operations theory holds that the seamless networking of friendly force elements will bring about an increase in combat power (Alberts, Gartstka, & Stein, 1999). The basic idea is that related mission applications should be integrated into a single managed "C2 Node".

Included in this technology transition is the advancement and implementation of an Effects Based Operation (EBO) methodology. The goal for the Air Force is to enforce a standardization of this methodology both in practice and in system development. This enforcement is occurring because operations have become complex and more difficult to keep track of, especially when joint forces are employed.

Up to this point, systems have been designed to support a kinetic (Strategy-to-Task), attrition-based approach to war. This approach extends to both strategy planning and assessment. This approach focuses the Strategy Planning Division primarily on tactical actions and a localized evaluation of mission outcomes in the form of battle damage assessment (BDA). Attrition-oriented approaches, focused solely on kinetic actions and localized results, prevents consideration of other important factors in modern military operations. These include economic, social, political and information/infrastructure factors that can substantially affect the end-game of an operation. Attrition-based approaches also do not allow for planning and/or re-planning based on an in-depth understanding of the effects that actions have produced. Lastly, it does not support an understanding of the duration of an effect, n^{th} order effects, and unintended effects.

In order to transition successfully from an attrition-based, strategy-to-task approach, the technology created to support the warfighter must be designed to better aid them in addressing the issues cited above: Relating actions to intended effects; performing predictive assessment in addition to assessment during and after execution; carrying out causal link analysis; and understanding nth-order effects within the context of economic, social, and political dimensions (in addition to traditional military considerations). With this in mind, the current efforts have focused on the Operational Assessment Team (OAT) residing in the Strategy Division. Little attention to date has been focused on this team and the important feedback that they provide in the overall EBO process. Our effort will provide this team with critically needed visualization technology to support analysis and decision processes that address the challenges outlined above.

The activity of the OAT in an effects-based environment focuses on addressing several critical questions:

Are we achieving the effects desired by the Joint Forces Air Component Commander (JFACC)?
What is our confidence that we are achieving the effects?
Does the intended effect have the desired duration; if not, how long and we expect the effect to persist?
Are there any unintended effects; if so, what implications do these have for the plan?
Do we need to modify our plan?
Do we need to modify our assessment strategy?

These are a few of the current challenging questions that a new technology has to support with decision aiding tools for the OAT. In addition to answering these questions, Effects-based Assessment (EBA) considers not just the direct effects of the attack, but also indirect effects in multiple domains, and the mechanisms that link the effects between those domains, systems and targets (Waller, 2003). When taking such a complex view to perform assessment, the tools designed to support this process have to be developed around a deep and rich understanding of the cognitive functions an operator uses to form judgments, carry out analysis and make decisions. Lastly there is a need to understand the expert novice differences. This will aid in understanding any workarounds performed and other strategies developed to perform assessment.

In the remainder of this paper we will discuss our integrated cognitive and systems engineering approach to the development of visualization technologies designed to support effects-based operational assessment. We first will describe our integrated cognitive and systems engineering approach. We follow this with a description of our visualization interface concept development. We end with a brief description of the evaluation of the concepts.

Cognitive Systems Engineering for Operational Effects Assessment

Our cognitive systems engineering (CSE) of the EBA domain emphasized five focal areas or views: Work management, cognitive work, products, collaboration and automation. The concepts comprising these views, along with the relationships between them, are shown in Figure 1. Each view is presented in Figure 1 as colored concepts related by one or more bi-directional relationships. All of the CSE analysis that we carried out conformed to this informal top-level ontology. While all five views are represented in our analysis, we concentrated the majority of our efforts on understanding the cognitive work requirements associated with EBA. It is the cognitive work associated with the job of assessment that drives the operational and functional support requirements for those activities comprising assessment. The concepts and relationships surrounding this cognitive work are shown to the right of Figure 1. The cognitive work required during EBA includes workflow, cognitive work requirements, information requirements that directly support the cognitive work, data and data sources directly supporting the information requirements, and constraints and dependencies that influence the organization of work flow.

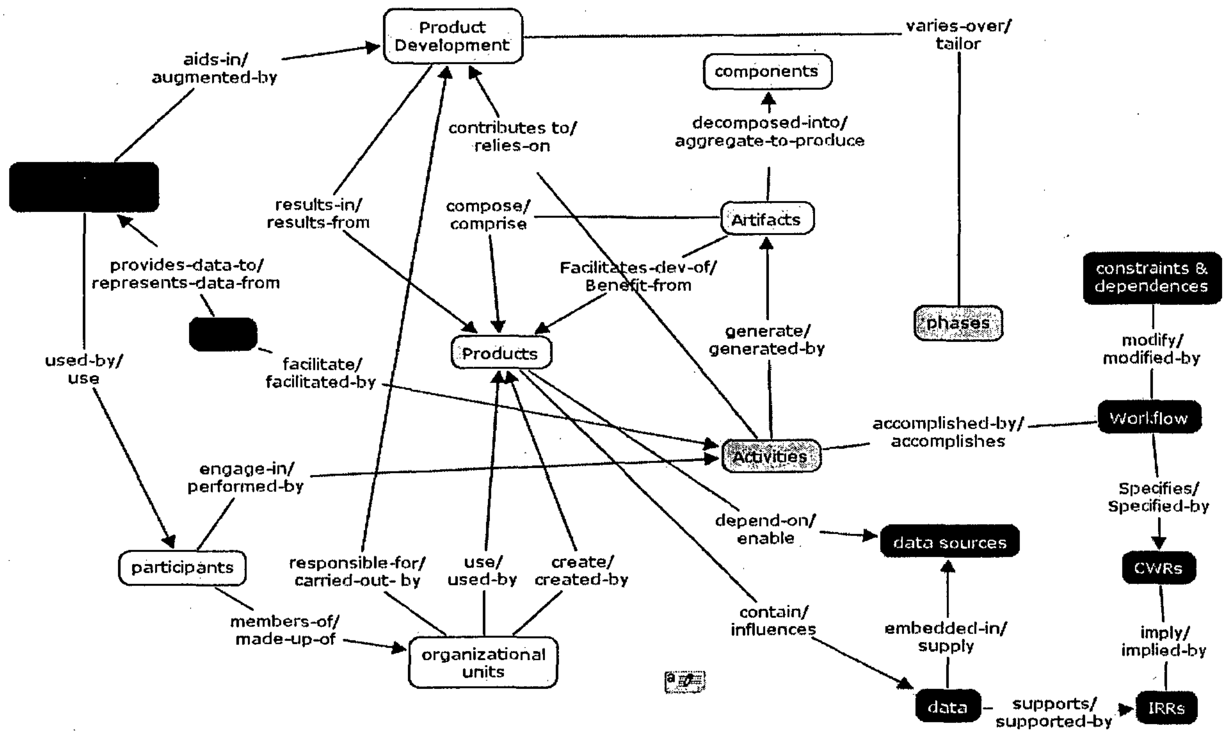

Figure 1: CSE Ontology for Analysis of the EBA Domain

Working with Air Force documents and subject-matter experts (SMEs) we defined 15 high-level functions representing the cognitive work associated with EBA (see Table 1). These were then decomposed into a series of activities representing the structure of each function. With operational activities as the centerpieces of each diagram, we then defined the work management strategies, products, collaboration and automation associated with each activity. In general, the work associated with operational activities is expressed as a relatively small set of perceptual and cognitive processes. Table 2 contains a listing of these processes. The method we used in constructing the concept maps required that each element of perceptual or cognitive work be stated in terms of these primitives. This is important for several reasons: (1) it allowed us to express the low-level work involved in EBA as a small set of primitives, thereby allowing us to better manage the move to system requirements in later stages of the design, (2) it provided a way to map our system design requirements to results in the human factors research literature and (3) it provided a bridge between the cognitive systems analysis and the system engineering model of EBA to be discussed below.

Table 1. EBA High-level Cognitive and Perceptual Work

Pre-execution	**Execution**	**Post-execution**
Assessment planning	Accrue evidence	Provide inter-division feedback on operational effectiveness
Determine adversary capabilities and likely COA	Analyze operational results	
Develop JAOP	Integrate BDA	
Develop STTM	Execution tracking	
OAT management of EBA	Integrate functional damage assessment	
Predict operational effectiveness	Integrate mission assessment	
	Integrate physical damage assessment	
	Integrate target system assessment	

Table 2. EBA Cognitive and Perceptual Work Elements

Comparison	Interpret
Inference	Integrate
Recognition	Derive
Decision	Extrapolate
Selection	Predict
Search	Correlate/associate
Monitor	Evaluate
Acquire	Identify
Communicate	Rank
Assess	

In the discussion that follows, we concentrate on activities comprising the execution portion of EBA. These include (1) accruing input from lower-level processes and from other data sources, (2) fusing the data, (3) analyzing the data, (4) determining if objectives were being met, (5) troubleshooting the plan (or the assessment indicators) if necessary, and (6) organizing assessment findings for dissemination to the JFACC and/or the strategy team.

Inspecting the categories of work appearing in each operational activity is informative in helping us understand the technology support requirements for the activities. Accruing evidence is primarily a process of acquisition and interpretation or assessment. Most of the acquisition processes defining the work of this activity included either actively seeking desired information or monitoring pre-determined information channels for useful information that could be acquired opportunistically. As information was obtained it was assessed or interpreted in terms of the plan in force for a particular mission.

Analyzing operational results, though containing many work elements ranging across 16 different perceptual and cognitive categories, consists almost totally of interpretation and assessment work. This seems reasonable, given that success in this operational activity must relies on combining large amounts of information from many sources into a coherent "story" and then trying to understand if the "story" is the right one within the context of the current objectives, tasks, indicators and timelines. The remaining perceptual and cognitive work for this activity exist only to support these other two primary functions.

We developed a hybrid concept map, which we termed "integrate mission assessment," that captured elements of both determining mission effectiveness and troubleshooting the effects-based plan when events demonstrated plan shortfall. From a cognitive systems engineering point of view this was an interesting activity. Whereas determining mission effectiveness involved a single process, "evaluate," troubleshooting the plan was a more heterogeneous process that included evaluating available information, making inferences about what went wrong, and making specific decisions about how to repair the plan.

In all, we found that all of the perceptual and cognitive work comprising the execution portion of EBA could be accounted for with 19 functional terms, as shown in Table 2. This is a slightly higher number of terms than was identified by Hale (1988) but significantly fewer than identified by Fineberg (1995). We are now working to determine the system design implications of each term.

The EBA concept maps then were mapped to system engineering requirements. This was an important step in ensuring that the CSE analysis results were represented in the overall system development. We accomplished this by mapping items within five cognitive system engineering categories to elements of traditional functional analysis. System engineering requirements analysis products then were developed from the functional analysis. These mappings are shown in Figure 2. The five CSE categories mapped information about the work domain, control tasks performed by assessors, strategies carried out in support of requirements, socio-organizational factors and human limitations and competencies. The mappings from CSE to functional categories were many-to-many, as would be expected for each of these broad CSE categories. The system engineering functional analysis, which now included the information from the cognitive system engineering analysis, formed the basis for development of system engineering requirements analysis products. These fell into three broad categories or views: Operational views, functional views and physical views.

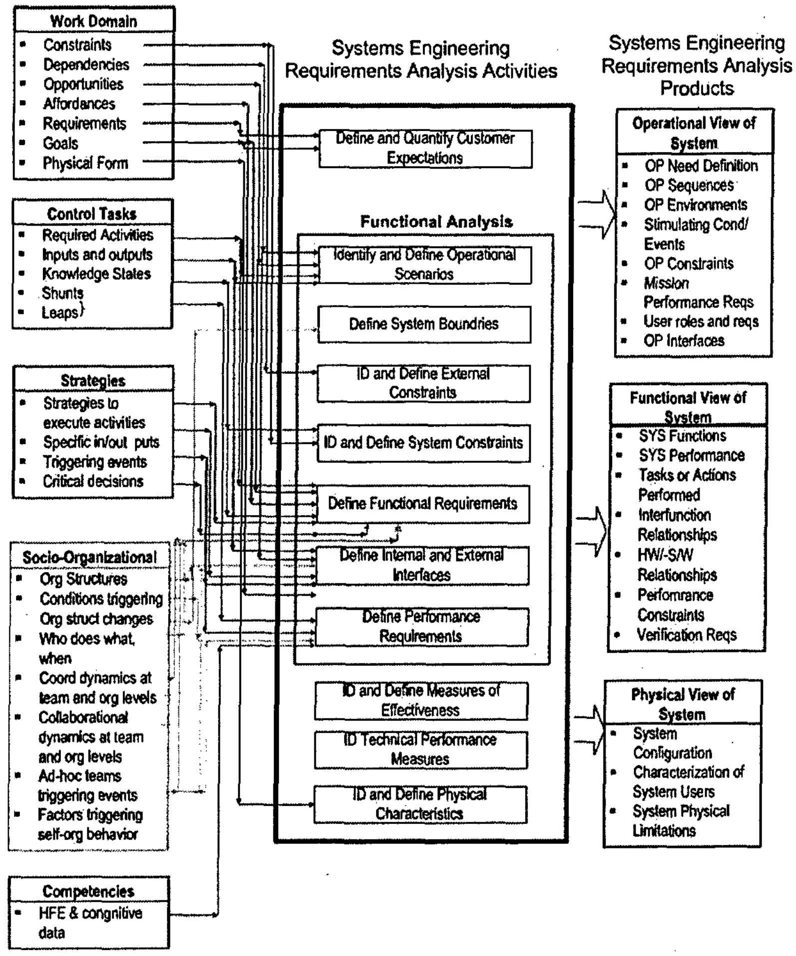

Figure 2. Cognitive Systems to Systems Engineering Requirements Mapping

All of the information from the previous analyses; along with EBA doctrine, concepts and other documentation, and SME input; was used to develop a set of system engineering models of EBA in CORE. CORE is a commercially available CASE tool that allows management of an entire development project. Modelers can include a wide range of information about system functionality, inputs and outputs, sequence, constraints and dependencies, triggering conditions and end-states, products and so on. The system also includes a discrete event simulation engine that enables exploration of tradeoffs and what-if analyses. Output can be in terms of any standard DoDAF formalism.

Our system engineering model consists of 108 functions focused primarily on the execution portion of EBA. The functions are organized hierarchically, as shown (in part) in Figure 3. Referring to this figure, each component function is shown as a block within its parent diagram. Functional boundaries for a particular activity are shown with block shading; light blocks are within a boundary while shaded blocks are outside a boundary. Sequence and flow logic also are shown in each diagram. Most of the detailed cognitive and perceptual work across the five top-level diagrams took place in support of analyzing operational results. This can be seen by considering the number of levels of decomposition needed to completely describe each function. A complete description of analyzing operational results required decomposition to eight levels, while adequate descriptions of the remaining four functions within execution required no more than 3 levels of decomposition. In order to preserve the information contained in the concept maps, as well as the mappings between concept map data and system engineering requirements, we placed an emphasis in CORE model development on capturing the cognitive and perceptual work within the functional system description. Thus, cognitive and perceptual work appears as separate functions in the lower levels of the CORE diagrams. When combined with their attendant inputs and outputs these work elements generate technology development and visualization requirements directly.

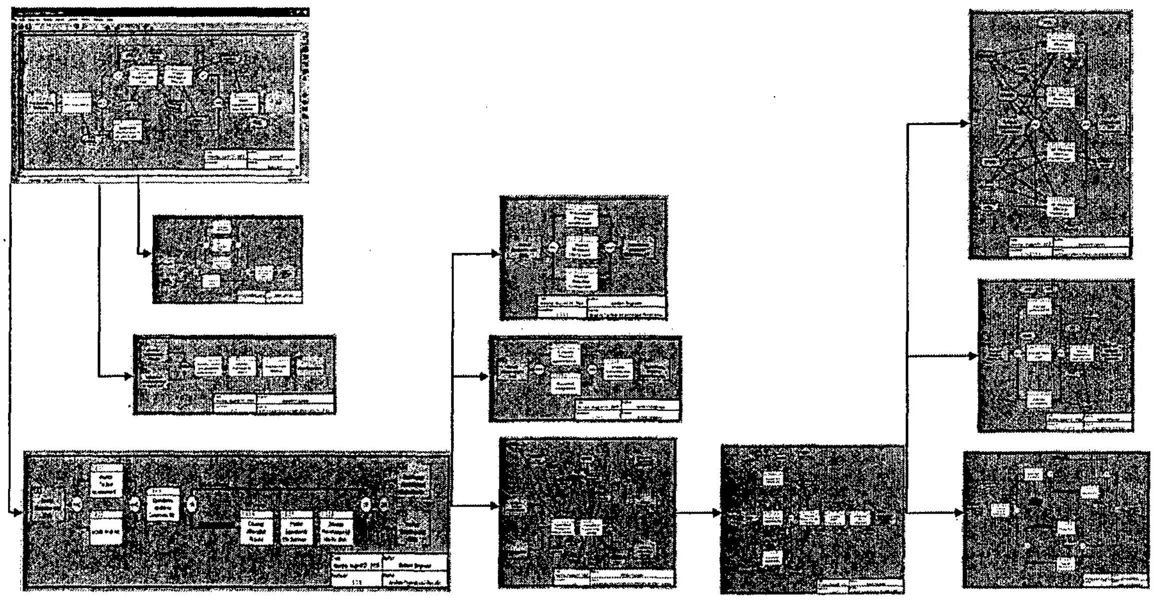

Figure 3. A Portion of a System Engineering Model for Operational Assessment

The completed CORE diagrams formed the basis of requirements identification. The CORE package automatically generates system requirements. Using this facility we generated a requirements set consisting of 330 items. The development team then edited this set to determine what items fell within the scope of the development program. Because the cognitive and perceptual work from the concept mapping analysis was distributed across the system engineering model hierarchy, the requirements associated with this work also appeared hierarchically.

Visualization Interface Concept Development

Based on our in-depth analysis, the fundamental process of assessment was broken down into five categories: Request for Information (RFI), Evidence Accrual, Analyze Operational Results, Determine Effectiveness of Air Operations in Achieving Objectives, and Develop Assessment Briefing. These five high level categories encompass the processes, tasks, data, and information needed to perform operational assessment during execution. By breaking assessment into these categories, we were able to fully analyze the data. This in turn helped us to ensure that the tasks and decision making skills were supported in the design of the concepts. Below, we will go into more detail about the categories and discuss initial concept ideas.

Request for Information

There are several tools that support the RFI generation process. However, many of these either are not being used or have not been deployed. It will be important to provide and deploy a tool that makes this task consistent and easy to carry out. If such a tool is available, the process may then be standardized. In addition to having standardized processes in place it should also be possible to save the RFIs themselves in an archive. This makes them available for possible future use, thereby improving the efficiency of assessors over time. Functionality that should be included in a RFI support module are:

- What is being requested.
- Who is being asked for the information.
- The type of data needed.
- Data format.
- Data request deadline.
- Any additional comments on specifics of the data needed.

Evidence Accrual

Once data have been requested, the assessor then needs to manage the data in a meaningful way. This implies storing the data and naming the file in a convention that the user will understand and that will facilitate locating the file rapidly. Users must be able to allocate the data to a particular day, objective and/or action. This allows the assessor to view at a glance which objectives/actions have data collected against them, giving them an indication what data still needs to be collected. However, this high level glance is not enough to tell the assessor anything about the confidence in that data. This shortfall raises the need for a confidence-based rating system. Confidence ratings should include source, reliability, and validity. These attributes are important because different data types and their original sources give assessors an indication of the true state of the event taking place. Some sources are more reliable than others, however, and in many cases data will be in conflict. When conflicting data are gathered, assessors will naturally rely on the data that they believe is more reliable. Their beliefs might, or might not be, correct. Thus, the visualization system should provide cues about data source, reliability, validity and the age of the data.

Analyze Operational Results

As the operation proceeds and data are streaming in, assessors need to evaluate that data against the plan of the day to estimate progress toward intended effects. The plan is based on actions that need to be taken to successfully achieve an Operational Objective and/or an Effect. One critical issue associated with this process is that data often are delayed, noisy, or missing entirely. The assessors must make their estimates in the face of this uncertainty. Much of the available data will be presented in the form of summarized tactical results; including Battle Damage Assessment (BDA), Mission Effects Assessment (MEA), Mission Assessment (MA); and intelligence data. From this information the assessor will compare actual versus planned actions. This allows the assessor to determine if the plan, in terms of actions per time period, is proceeding as intended or not. This in turn allows the assessor to make weight of effort and other recommendations for upcoming days.

Once tactical results summaries have been obtained and analyzed assessors must determine if the intended effects are being achieved. The complexity of the battlespace, combined with multidimensional considerations and the use of joint and coalition forces, has vastly increased the complexity of these estimates (Diehl & Sloan, 2005). The challenge is further heightened by the need to evaluate unintended and n^{th}-order effects, and to convert qualitative evaluations into quantitative estimates. Current implementations of technology intended to address these challenges rely on attrition-based metrics. For example, one approach is to use Desired Mean Point of Impact (DMPI) as a count to assess whether the effect is being achieved. However, this method fails to support the kind of assessments required to relate actions to intended, unintended and n^{th} order operational effects.

In order to analyze the data to see if an effect is being achieved the assessor needs to understand the battlespace and have data that pertains to the actions and/or tasks that were intended to cause an effect to occur. Once these data are acquired, the assessor can then find indications of the effect being achieved by evaluating the adversary's actions and systems. In addition, assessors can plot the actions and their associated effects on a map. The data then can provide insight into any unintended, 2^{nd} order, and/or 3^{rd} order effects.

Determine Effectiveness of Air Operations in Achieving Objectives

The difference between this category and Analyzing Operational Results is the fact that the assessor is now comparing their analysis of their operational results to the overall Operational Objective. The overarching goal of an operation is to successfully complete and achieve an Effect and the Operational Objectives in the time allotted.

Develop Assessment Briefing

The OAT chief briefs the JFACC twice daily (morning and evening). The preparation for these briefings is often time consuming, diverting resources away from their primary job of assessment. The issues surrounding preparation of assessment briefings are similar to those of RFI generation and management: There currently are no standardized tools that have been deployed to aid in this task. The fundamental goal of our system will be to help assessors reduce the time spent in developing these briefings. The first design task is to standardize the briefing. This standardized format would include an explanation of status in terms of actions and effects, a predictive analysis, and recommendations. Based on this, the ideal would be to directly take a snapshot of the current status of an Objective and place that into the briefing in summary form. If this summary needs to be modified assessors should be able to do so within the briefing through links to primary data held elsewhere within the assessment system. Currently, this concept needs further analysis to determine what additional data might be needed, and how the snapshot can be transferred seamlessly into a briefing. But, as stated before, the goal is to reduce the time spent in developing these presentations so that the assessor has more time to perform other tasks.

Concept Evaluation

Throughout our concept development we have involved several subject matter experts (SME). This process has helped us to ensure that 1) We were supporting the tasks that need to be supported, 2) the concepts were usable and made sense, and 3) we understood the relationships between the realities of the domain and doctrine. The process from data collection to design included analyzing the data we collected and developing initial concepts. These initial concepts were then evaluated by our SMEs. Evaluation consisted of working through each of the assessment tasks using the visualization concepts within the context of a short operational scenario. As the evaluation progressed difficulties in procedure, workflow, data access, interpretation of visualization elements and any comments on the part of the SMEs were documented and categorized with respect to the cognitive work elements and system requirements. We then modified the concepts based on these data.

This evaluation process will take place iteratively until the "final" concepts have been designed and are ready for coding. Once coding is done, the prototype will be taken to a major Air Force experiment in April, 2006 to be evaluated in an operational setting.

Conclusion

Today's operations are exponentially more complex than before, owing to considerations of multiple, interacting domains; a need to assess causal linkages across lines of effect; a need to assess n^{th}-order effects; and the requirement to "roll up" operational results across multiple levels of effect. New technologies being developed will need to enhance operators' situational awareness, help them effectively manage uncertainty and risk, and aid them in formulating and executing decision making strategies. These types of tools are critical to executing a successful campaign. During Operation Iraqi Freedom, tools such as these were not available to the OAT. Without such tools the OAT found it difficult to evaluate the effectiveness of operations. An effective visualization system can help tremendously with these challenges by supporting the assessment warfighter with procedures and processes and by making available the data required to accurately assess progress toward effects. In short, helping the OAT to understand where they were, where they are and where they will be informs assessment, thereby allowing the OAT to keep the entire AOC current and well-informed as to the effectiveness of an operation.

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